EFFECT OF TRANSPORT LAYER SYSTEM ON SUCTION DISTRIBUTION FOR TROPICAL RESIDUAL SOIL SLOPES

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I recognise and appreciate the life-long influences of my parent, my teachers, my wife, my children, my family and my friends, whom have been the source of inspiration in my life. This thesis is dedicated to all of them.

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ABSTRACT

Substantial surficial deposits of many tropical climate regions are covered by tropical residual soils. The weathering process forms a layered sloping soil of Grade VI and Grade V soil mantle with variable hydraulic conductivities, k_{sat} which creates capillary barrier effect at the interface of Grade VI and Grade V soil layers. Although the capillary barrier effect impedes downward water infiltration, the water diversion capacity is limited and the moisture content increases at the interface that can lead to potential slope failure. Hence, this study investigates the effects of employing transport layer to increase the diversion capacity at the interface of Grade VI and Grade V soil layers via laboratory experiments, field monitoring and numerical modelling. A laboratory physical slope model was developed to perform infiltration tests with five (5) configuration schemes of Grade V and Grade VI soils sandwiched by four (4) different types of transport layer, i.e. Gravel, Drainage Cell (DC)+Gravel, Sand and DC+Sand, and without transport layer. A total of thirty two (32) infiltration tests were performed in this study. Three research plots i.e. a control plot without transport layer and two (2) plots with sand transport layer as well as with gravel transport layer were constructed and instrumented to monitor rainfall, runoff, amount of diverted water and matric suction distribution. The monitoring was performed during wet period from September 2014 to January 2015 where the soil experienced high water content but low matric suction. Subsequently, the two-layered slope with and without the transport layers was numerically simulated using a finite element method to validate the field data and to determine the best modelling scheme to represent the residual soil slope model with transport layers. The results of the laboratory experiments clearly shows that the transport layer sandwiched between the Grade VI and Grade V soil layers was capable of diverting the infiltrating water above the interface. There was a significant increase of matric suction measured at the interface of soil layers with DC + Gravel transport layer as compared to that without the transport layer especially for 2-hr and 24-hr rainfall intensities while the effect was insignificant for 7-day rainfall intensity. Field monitoring also indicates that the initial matric suction value in the control plot responded to the infiltration and reached a matric suction value that corresponds to the breakthrough suction of 5.0 kPa after series of rainfalls. However, the initial matric suction values were relatively maintained in the plots with transport layers to indicate that the transport layer played the role of increasing the amount of diverted water at the interface. The finding was supported by the results of amount of diverted water collected at the research plots. Continuum model is capable of modelling the effects of employing transport layer at the interface by subdividing the layer into multiple isolated zones with different average k_{sat}. The results of the analysis demonstrated that the capability of transport layer to maintain the matric suction and to divert water was governed by the contrast in the k_{sat} where the higher k_{sat} of gravel shows a better performance as compared to sand. A combination of initial suction at 30 kPa, 0.5 m thickness of sandy silt (Grade VI), 0.3 m thickness of gravel transport layer and 21° slope angle resulted in a diversion length of more than 15 m. However, the lower initial suction value due to rainfall infiltration during wet period yielded a shorter diversion length.

ABSTRAK

Kebanyakan endapan permukaan bagi kawasan iklim tropika adalah diliputi tanah baki tropika. Proses luluhawa membentuk satu lapisan tanah bercerun dari Gred VI dan Gred V dengan keberaliran hidraulik tepu, k_{sat} berbeza yang menyebabkan berlakunya kesan halangan rerambut di antara muka lapisan Gred VI dan Gred V. Walaupun kesan halangan rerambut ini menghalang penyusupan air lebih dalam, namun kesan ini akan hilang akibat saliran yang kurang baik dan berupaya mengagalkan cerun kerana tanah kandungan lembapan meningkat di antara muka. Oleh itu, kajian ini menyiasat kesan penggunaan lapisan pengangkut untuk meningkatkan kapasiti lencongan air di antara muka lapisan Gred VI dan Gred V melalui eksperimen makmal, pemantauan tapak dan permodelan berangka. Satu model fizikal cerun telah dibangunkan dalam makmal untuk ujian penyusupan di mana lima (5) skema konfigurasi lapisan Gred VI dan Gred V mengapit empat (4) jenis lapisan pengangkut iaitu Kelikir, Sel Saliran (DC)+Kelikir, Pasir dan DC+Pasir, dan tanpa lapisan pengangkut. Sejumlah tiga puluh dua (32) ujian penyusupan telah dilakukan bagi kajian ini. Tiga plot kajian iaitu satu plot kawalan tanpa lapisan pengangkut dan dua plot mempunyai satu lapisan pengangkut pasir dan satu lapisan pengangkut kelikir telah dibina bagi merekodkan kadar hujan, air larian, jumlah air lencongan dan taburan sedutan matrik. Pemantauan tapak dijalankan dalam musim hujan bermula dari bulan September 2014 hingga Januari 2015 ketika tanah mengandungi kandungan air yang tinggi tetapi sedutan matrik yang rendah. Seterusnya, cerun dua lapisan tanah ini yang mempunyai lapisan pengangkut dan tanpa lapisan pengangkut telah disimulasi secara pemodelan berangka menggunakan kaedah unsur terhingga bagi mengesahkan data lapangan dan untuk mengenalpasti pemodelan berangka yang terbaik bagi mewakili model cerun tanah baki yang mengandungi lapisan pengangkut. Keputusan eksperimen makmal jelas menunjukkan lapisan pengangkut yang diapit antara lapisan Gred V dan Gred VI mampu melencong air yang menyusup di atas permukaan. Terdapat peningkatan yang ketara pada sedutan matrik yang diukur pada di antara muka bagi lapisan tanah dengan DC+lapisan pengangkut kerikil berbanding tanpa lapisan pengangkut untuk keamatan hujan 2 jam dan 24 jam, tetapi hanya sedikit perubahan bagi keamatan hujan 7 hari. Pemantauan tapak pula menunjukkan bahawa nilai sedutan matrik awal berubah dalam plot kawalan akibat tindak balas terhadap penyusupan air hujan dan mencapai nilai akhir yang sama dengan sedutan matrik pada keadaan bulus iaitu 5.0 kPa selepas beberapa siri hujan. Namun, nilai sedutan matrik awal adalah relatif dengan nilai akhir bagi plot dengan lapisan pengangkut menunjukkan keberkesanan keupayaan lapisan pengangkut untuk meningkatkan kapasiti lencongan air di antara muka tanah. Hasil keputusan ini disokong dengan jumlah air yang dilencongkan meningkat di plot tapak kajian tersebut. Model selanjar berkebolehan memodelkan kesan penggunaan lapisan pengangkut di antara muka tanah ini dengan kaedah membahagikan lapisan tanah kepada berbilang zon terasing yang mempunyai berlainan purata k_{sat}. Keputusan analisis model ini menunjukkan bahawa keupayaan lapisan pengangkut untuk mengekalkan sedutan matrik dan jumlah air yang dilencongkan dipengaruhi oleh k_{sat} di mana nilai k_{sat} bagi kerikil yang lebih tinggi menunjukkan prestasi yang lebih baik berbanding dengan pasir. Gabungan sedutan matrik permulaan pada 30 kPa, ketebalan 0.5 m bagi tanah sandy silt (Gred VI) dan 0.3 m bagi lapisan pengangkut kerikil serta sudut cerun 21° mampu menghasilkan panjang lencongan sehingga 15 m. Bagaimanapun dengan nilai sedutan matrik permulaan yang lebih rendah akibat penyusupan air semasa musim hujan menghasilkan panjang lencongan lebih pendek.